# Large-Actuator-Count MEMS Deformable Mirror Development

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Small
Business
Innovation
Research

# PTT489-5 Segmented PTT Deformable Mirror

***Iris AO, Inc.***
***Berkeley, CA***

## INNOVATION

PTT489 Segmented MEMS Deformable Mirror: A 489 actuator, piston/tip/tilt positionable deformable mirror used to correct optical aberrations.

## ACCOMPLISHMENTS

- Conducting production runs
- Dramatic improvement in reliability and failure proofing
- Beta devices delivered with > 99% segment yield
- Segment figure < 5 nm *rms*
- Dielectric coatings demonstrated
- Path-finding research demonstrating 3000 actuator devices
- Beta devices purchased from NASA GSFC and by customers using them for other SBIR projects

## COMMERCIALIZATION

- PTT489, 489 actuator piston/tip/tilt deformable mirror
- 6 patents awarded, 1 patent pending
- PTT111 and PTT489 DM currently being sold
- DMs purchased by NASA/GSFC and researchers in vision science, astronomy, and defense
- Factory calibrated position controller linearizes operation and limits operation to safe bounds.
- Larger stroke than competing large-actuator technologies while maintaining speed
- Rigid mirror segments enable dielectric coatings

*PTT489-5 DM*

## GOVERNMENT/SCIENCE APPLICATIONS

- High-stroke micromachined deformable mirror to correct aberrations caused by turbulence or to actively correct optical system aberrations
- Extend to 1000 actuator devices for high turbulence imaging and laser communication applications (DOD) and 3000 actuators for high-contrast imaging applications (NASA)
- Actual applications: Nulling coronagraphs for exoplanet imaging, Atmospheric turbulence compensation for free-space laser communication, laser guide star uplink correction
- Actual applications: Potential applications: High-speed focus correction for laser machining
- Phase III purchase of DM by NASA GSFC for Extrasolar Planetary Imaging Coronagraph (EPIC), GSFC, Clampin et al.
- Purchases of PTT489 by DOD SBIR winners using DM for their projects

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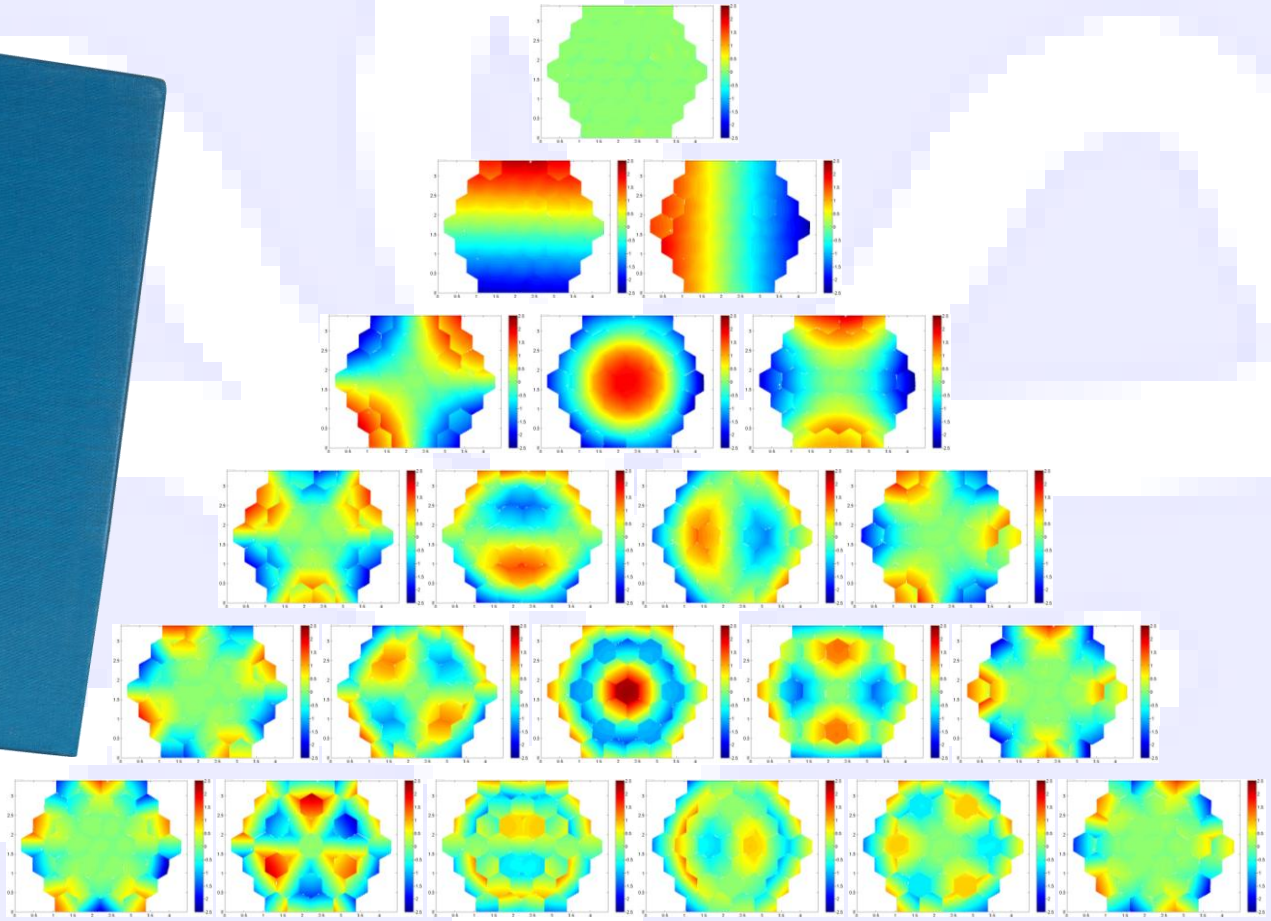
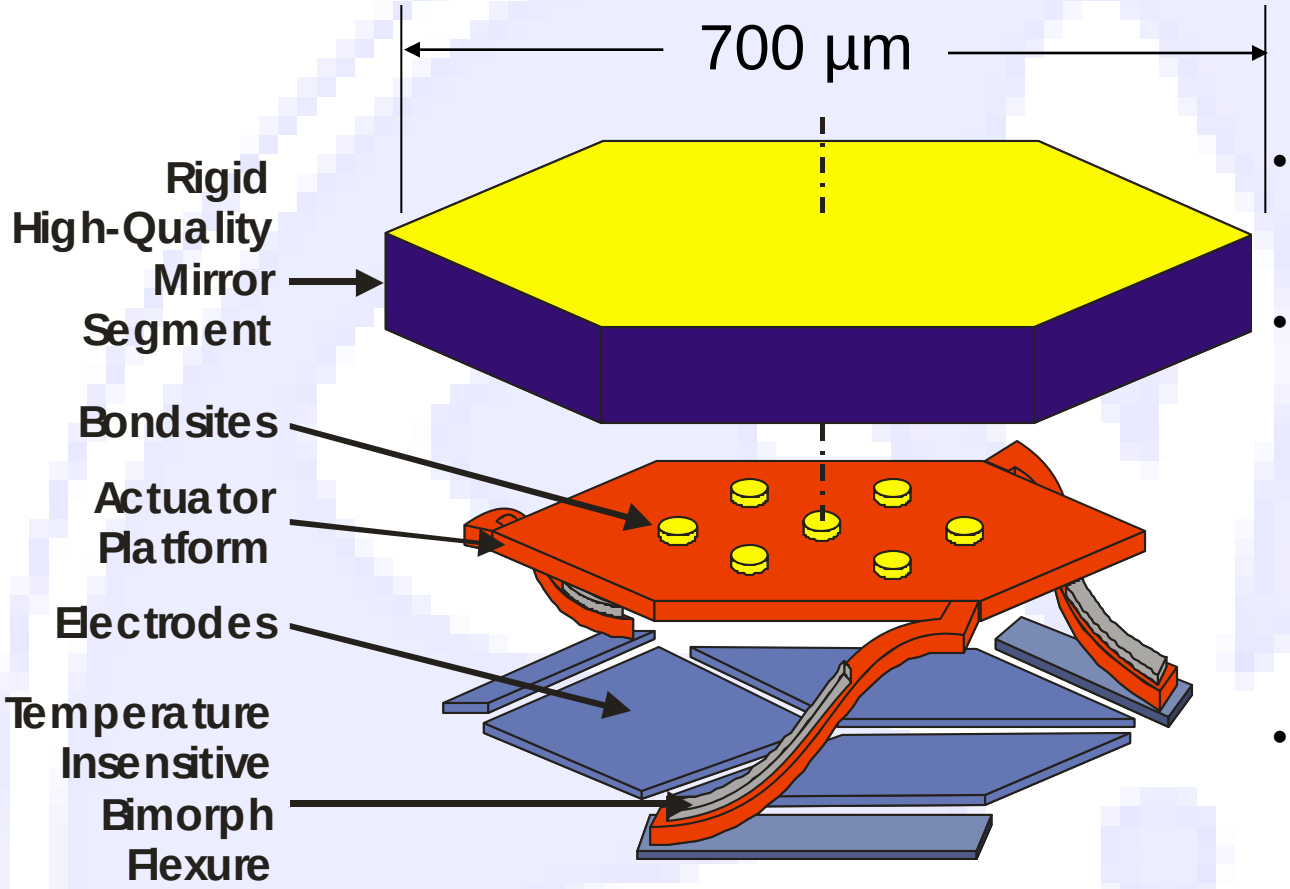
# Outline

- **Background: *PTT111-X (S37-X)***
- **PTT111 Improvements**
- **Scaling up: *PTT489-X and beyond***
- **$10^3$ segment DM pathfinding research**

# PTT111: *A Solid Foundation*



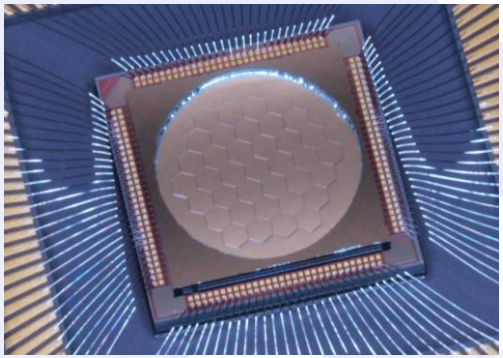
# DM Segment Schematic




- 3 DOF: Piston/tip/tilt electrostatic actuation
- Hybrid fabrication process
  - 3-poly surface micromachining
  - Single-crystal-silicon assembled mirror
- Unit cell easily tiled to create large arrays

# 1st Generation DM Attributes

- High Stroke: 5 µm, 8 µm
  - 10+ µm in controlled environments
- Flat mirror segments: < 30 nm *rms*
  - 0.25 – 4 nm PV bow /°C
- Fast mirror rise time
  - 120/140 µs rise/fall times, 20-80%; 1.63 µm, 36 V
- Precision factory-calibrated controller
  - Linear, open-loop operation
  - Implements position limiting
- Compact drive electronics
- Open-air operation
  - Tested >1000 hrs, 20-70% RH



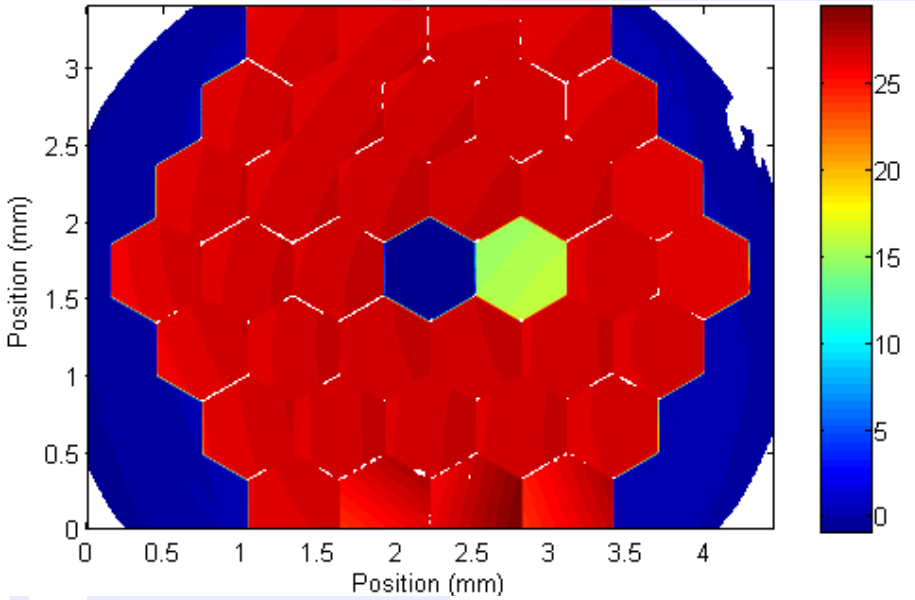

**Smart Driver II – 128 USB**
- 128 Channels
- High resolution
  - 14 bit, 200 V
- Low Noise:< 4mV *rms*
- Factory calibrated

# PTT111-X Design and Process Improvements: *Better, then Bigger*

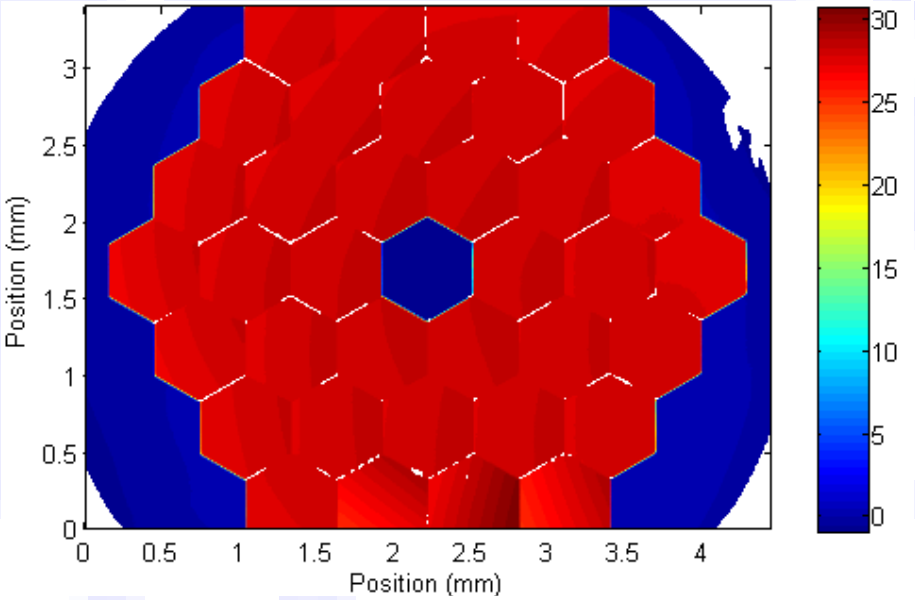
# PTT111 DM Improvements

- Flatter mirror segments
  - <5 nm rms
- Improved reliability
  - Snap-in prevention structures
- Relatively high-laser fluence demonstrated
  - Off-the shelf DM w/ protected-aluminum coating: ~95 W/cm$^2$
- Dielectric coatings demonstrated

# Anti Snap-In Device: *After 100,000,000 Snap-In Events*




**Segments Over Driven**




**Voltage Removed**

- Center segment fails because no snap-in protection
- Adjacent segment with protection survives
  - Testing stopped after 100,000,000 snap-in events with no failure

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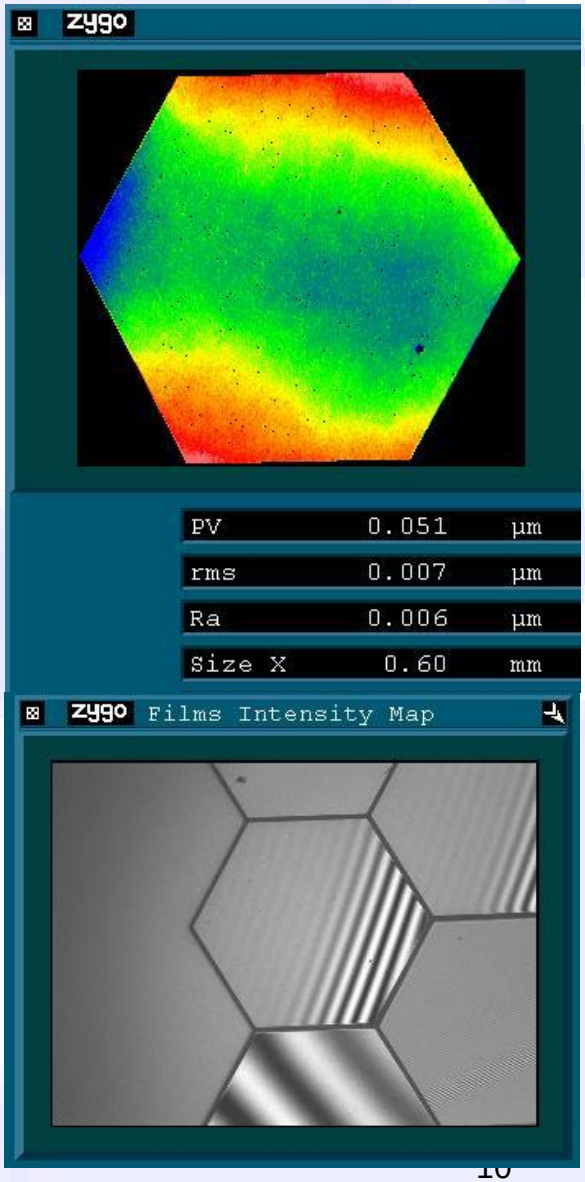
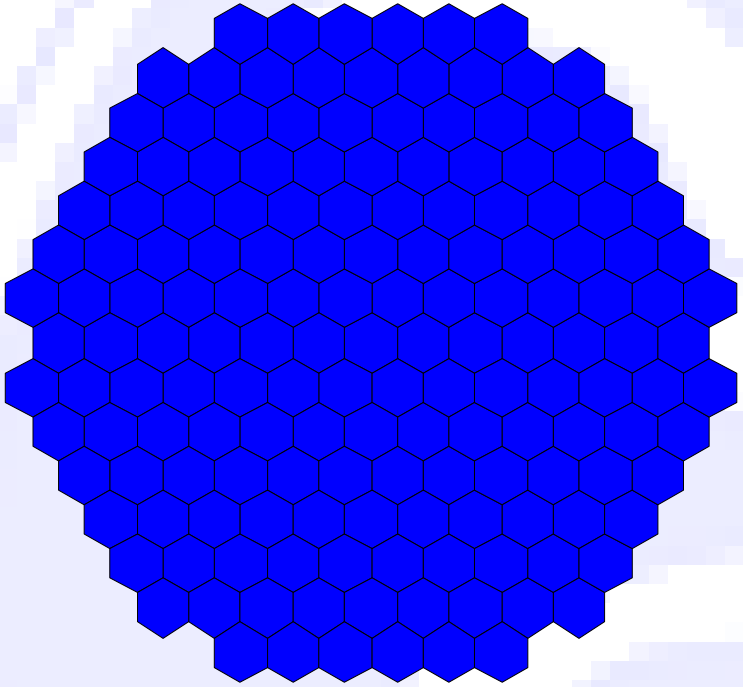
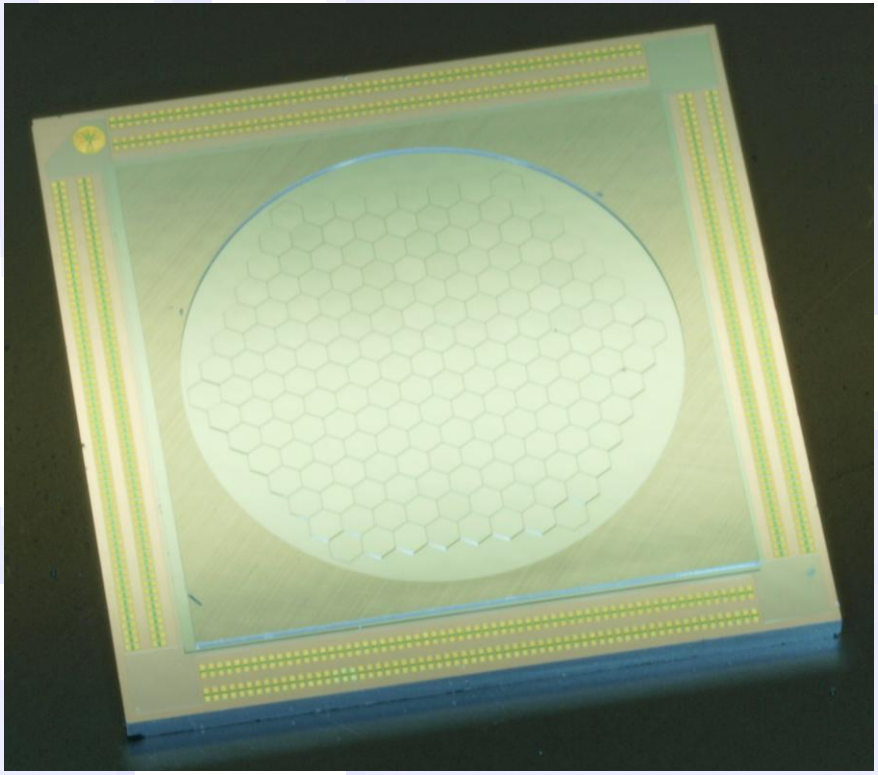
# High-Quality Dielectric Coatings

- **>99.9% reflectance dielectric coatings @ 532 nm**
  - **< 30 nm *rms* residual surface figure errors**
  - **~1.5 µm thick coating**
  - **Backside stress compensation layer**
- **Protected-Al coatings survived ~95 W/cm$^2$**
  - **Off-the-shelf DMs**
  - **Laser testing done at Laboratory for Adaptive Optics (LAO)**
- **Expect off-the-shelf dielectric coated DMs to be at least 10X higher**

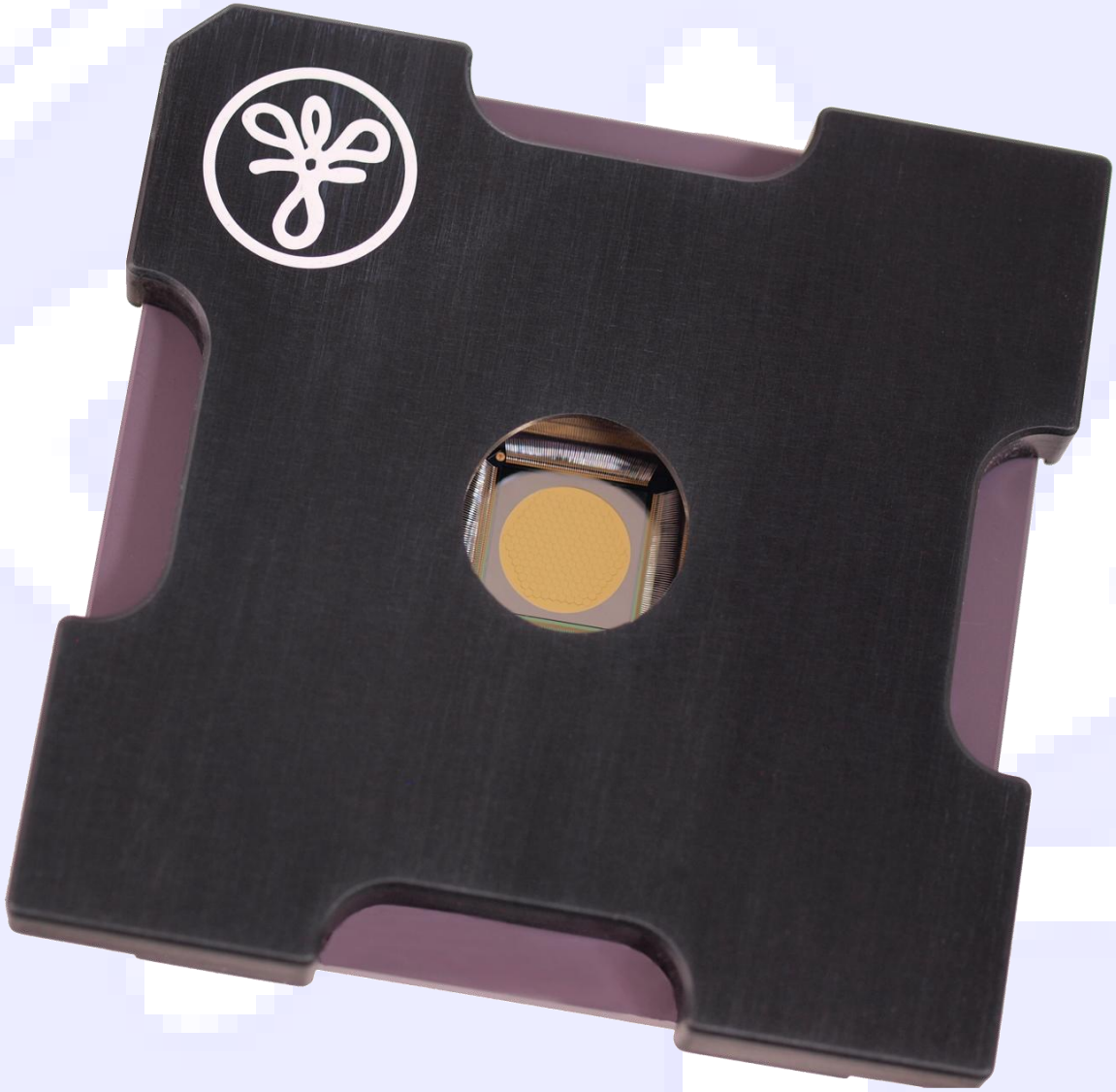


# Scaling Up: *PTT489-X DM*

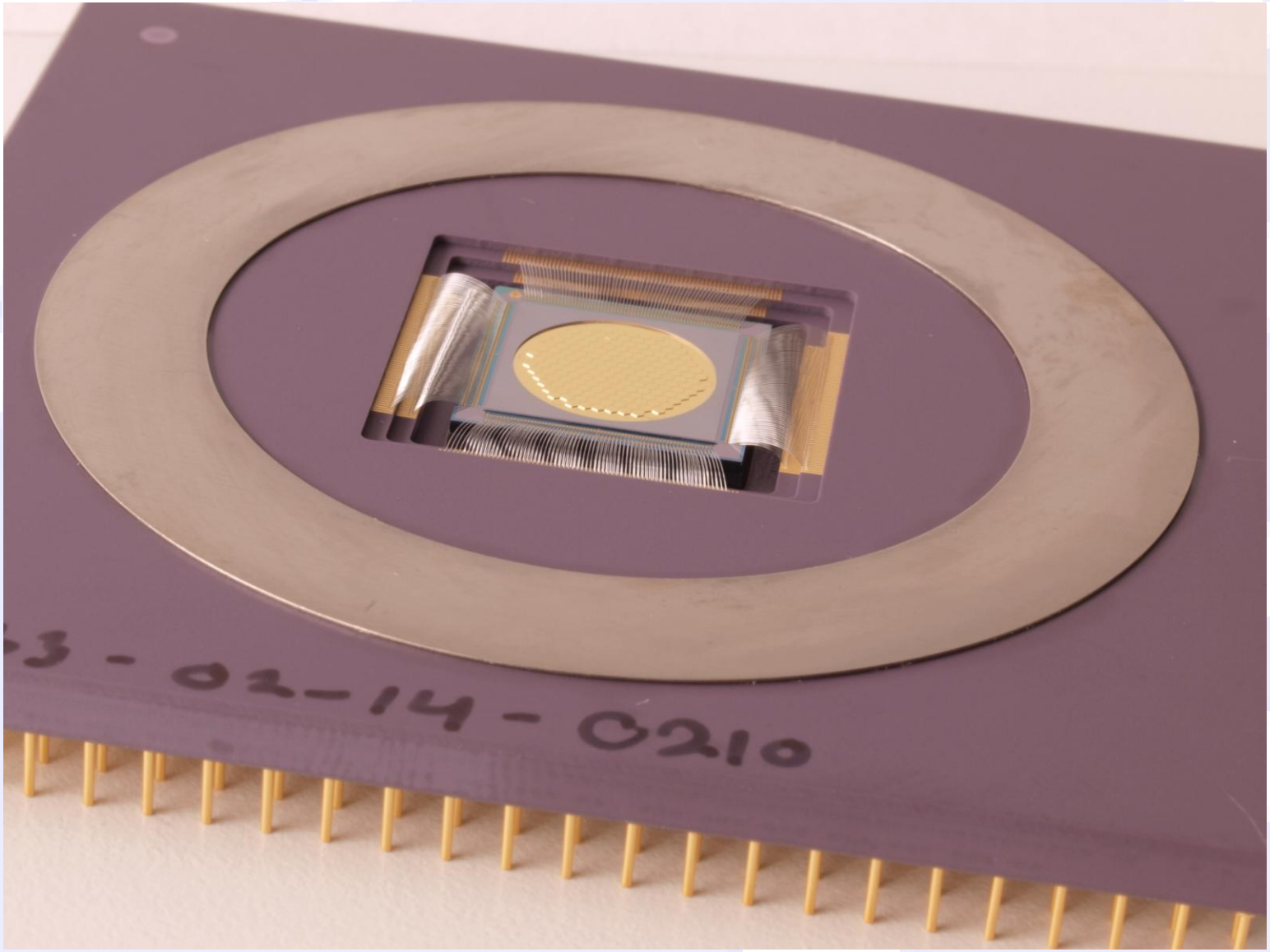




# PTT489-5 DM with Removable Cover



# PTT489-5 DM



# 1st Generation DM: *PTT111*

- **PTT111 used to develop basic systems and conduct testing**
  - **MEMS process development**
  - **Electrical characterization**
  - **Calibration**
  - **Software drivers**
  - **AO controllers**
  - **Reliability testing**
  - **Optical coating development**
- **Most aspects were tailored to PTT111**

# Scaling Up: *Creating an Extensible Design*

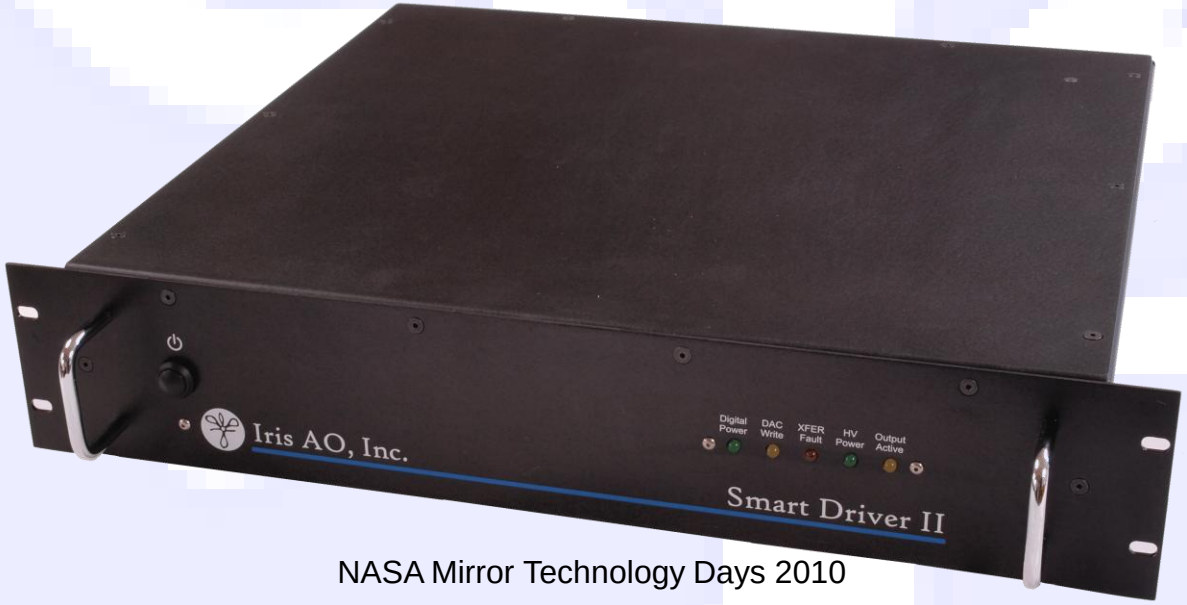
- MEMS design/process inherently scales well
  - Demonstrated stepper and contact photolithography
  - Existing design extensible to ~4000 actuators
    - Larger possible with development of interconnect
- New electrical tester for MEMS testing and characterization
  - Extensible to > 10,000 of actuators
- New calibration interferometer (ARRA Stimulus grant from NIH)
  - Larger FOV
  - Precision field stitching
    - Extensible to 100 mm aperture
- New PC-based software driver
  - Unlimited extensibility
  - Much faster update rates

# MEMS Process Development

- **Standing start to delivery of beta devices in <2 years**
- **Timeline**
  - **Tape out**
    - **May 2008**
  - **Actuator mechanical-only run**
    - **August 2008**
  - **Actuator electrical run**
    - **March 2009**
  - **Mirror wafer run**
    - **August 2009**
  - **Beta device delivery**
    - **March 2010**
  - **Production runs:**
    - **Mirror wafers: June 2010**
    - **Actuator wafers: August 2010**

# PTT Controller Speed Enhancements

- PCI/PCIe interface: v1.0
  - 2.5 kHz array update rates for PTT111 DM controller
- PCI/PCIe driver: v2.0
  - 6.3 kHz PTT489 array update rates
- Custom FPGA PTT controller demonstrated
  - Array update rates > 35 kHz



# Pathfinding Research: 3x$10^3$ Actuator DMs

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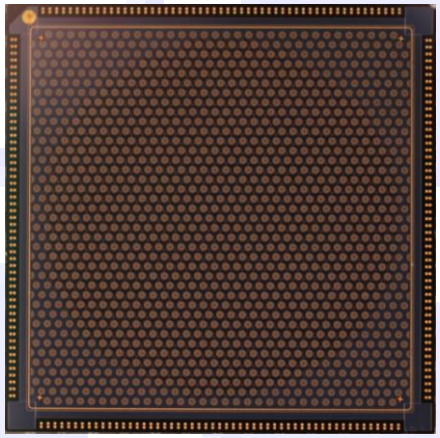
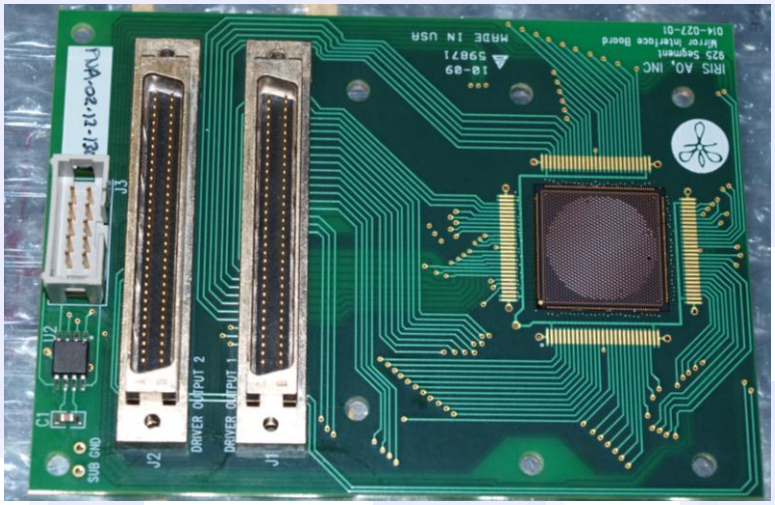
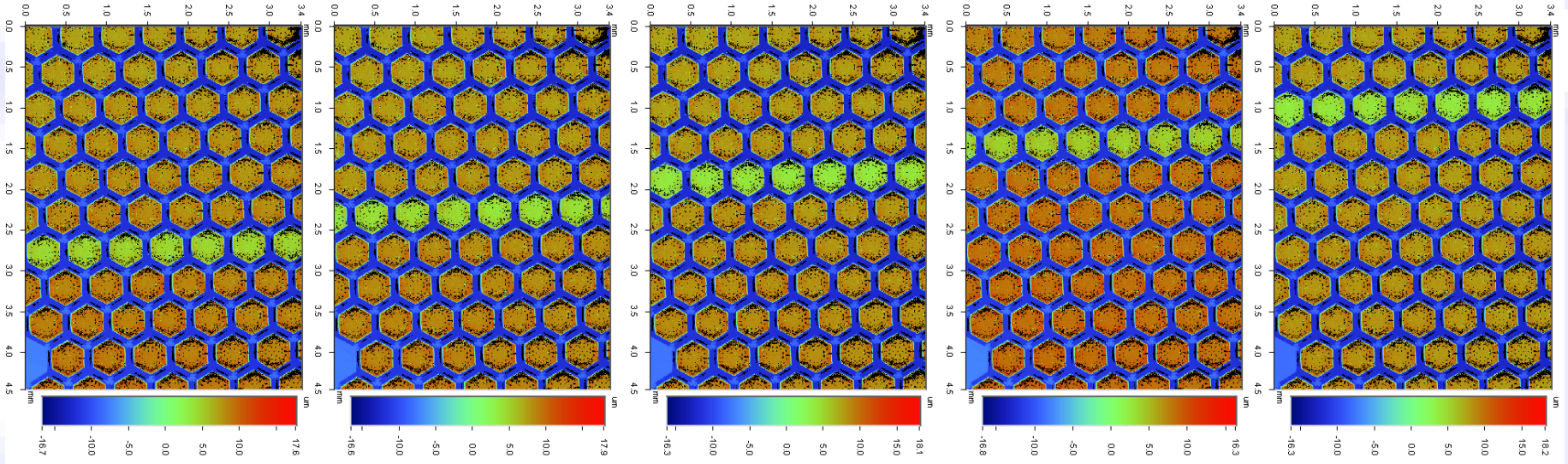
# $10^3$ Segment DM Path-Finding Research

**925 Segment Path Finder**



**20.088 mm**



# Summary

- PTT111 DM Improvements
  - Flatter segments
  - Faster interface
  - Dielectric coatings
  - Anti snap-in devices
- Technology scaled to PTT489
  - Beta DMs delivered
- All infrastructure revamped to be extensible
- Path-finding research demonstrates ability to scale to $3x10^3$ actuator DMs

# Acknowledgements

## Funding Sources

- NASA – SBIRs, (DM control, DM Fabrication)
  - Phase I/II: NNG07CA06C, Phase I: NNX09CE01P
- Center for Adaptive Optics (DM Process Development)
  - National Science Foundation Science and Technology: No. AST – 9876783
- National Eye Institute – Phase II SBIR (DM Process Development)
  - 2 R44 EY015381-02A1
- National Science Foundation – Phase II SBIR (2-Poly Process Development)
  - DMI-0522321

## R&D Fabrication Facility

- Berkeley Microfabrication Laboratory

## Research Collaboration

- Berkeley Sensor & Actuator Center